

Feasibility Study of Casing While Drilling Application on Geothermal Drilling Operation

Bonar T. H. Marbun, Widiyanto, Yudhistira Adinugratama, and Bramantyo E. Kurnianto

Magister Program in Geothermal Technology, Institut Teknologi Bandung, Jl. Ganesha 10 Bandung, 40132, Indonesia
bonar.marbun@tm.itb.ac.id

Keyword: drilling, casing while drilling, lost circulation

ABSTRACT

Geothermal is one of the energy that formed inside the earth. This thermal energy is contained in the fluid that stored in the reservoir. To utilize this energy, it is needed to drill and produce the fluid to the surface. The geothermal rock formation is usually igneous or metamorphic rock that has a lot of fracture and high temperature. The presence of these fractures makes loss circulation even total loss as a common problem and lead to problems for the like of stuck pipe. One way to overcome these problems is drilling with Casing While Drilling (CWD) method.

CWD has been widely applied in the oil and gas drilling operation. In principle, CWD is a drilling method by replacing the use of drill pipe with casing as the drill string so drilling and cementing operations can be performed simultaneously. In the oil and gas drilling operation, CWD shows a high performance drilling operation because it produce a gauge well, better wellbore stability, less possibility of loss circulation because of its plastering effect, and no need for tripping out so that drilling operation can be done safely and economically. Based on the experiences of CWD in oil and gas operations with all of benefits, it should be able to be applied in the geothermal drilling operation. CWD's plastering effect will solve total loss problem. However, in designing CWD for drilling geothermal wells required additional attention in the selection of casing and BHA due to high temperature. The result of this study is CWD can be properly applied on geothermal drilling operation based on considerations for the likes of economically drilling operation benefits, technical design, drilling time reduction and risk of using CWD.

1. INTRODUCTION

Geothermal is thermal energy generated and stored in the earth. This thermal energy is contained in the fluid that stored in the reservoir. This thermal energy can be utilized by producing the fluid to the surface. Same as oil and gas production, it is needed a drilling process to produce the fluids. But it is not totally same as oil and gas sector since there is a different formation type to be drilled.

1.1. Geothermal Formations

Geothermal reservoir consists of metamorphic or igneous rocks such as granite, granodiorite, quartzite, and volcanic tuff. This kind of rock types have different characteristics compared to common rock types of oil and gas reservoir. These rocks are generally hard, abrasive, highly fractured and under-pressured. In the other hand, because of geothermal energy inside the fluid, this formation has a high temperature (production zone up to 350 °C). These conditions makes drilling is more difficult, rate of penetration and bit life are typically low, Cacini (1994), corrosion is often a problem, Holligan (1989), and loss circulation is frequent and severe.

The high productivity of geothermal systems is related to the high fracture permeability. The highly productive fracture system is required to make geothermal projects economically viable, but is also the basis of the endemic lost circulation problems encountered when drilling geothermal wells, Finger (2010).

1.2. Geothermal Drilling Problems

Geothermal well drilling operations have to overcome high temperature up to 350 °C. Many targets of wells in geothermal drilling are faults, fractures or fissures that have high permeability and are connected with the geothermal reservoir, Kesuma (2008).

When drilling is in progress, the presence of these fractures let the drilling fluid enter the formation easily which causes a loss circulation problem. Loss circulation in drilling operations is the loss of drilling fluid to pores of fractures in the rock formations. This loss is harmful for several reasons.

- When the drilling fluid is loss to the formation, it will not bring cuttings to the surface and stick the drilling assembly.
- Loss of drilling fluid to formation will be very costly.
- Production zone in geothermal field is usually a loss zone, so it will be difficult to solve the lost circulation problems while preserve the production ability.

Generally, geothermal formation can contain dissolved or free carbon dioxide (CO₂) or hydrogen sulfide (H₂S) gases. These gases can contribute to the corrosion problem on the casing. H₂S also presents a substantial safety hazard during the drilling process. These material limitations, and the associated safety hazards, increase the cost of drilling geothermal wells.

Based on problems stated above, there are common solutions to overcome those problems such as usage of lightweight fluids, lost circulation materials (LCM), and wellbore sealing which are generally used in oil and gas drilling operations. Lightweight fluids generally consist of three categories: air, foam and aerated fluids with a range of density. This technique generates a static head lower or slightly greater than pore pressure to avoid lost circulation problems. However, this technique is most likely to let an influx from the formation to the wellbore system, which causes an increase of temperature and existence of hazardous gases in wellbore. LCM and wellbore sealing have similar purposes which are reducing pore or fracture permeability, so the drilling fluid will not easily enter the pores or fractures into the formation. However, this technique cannot be used in production zone at geothermal field because it will reduce the production ability.

2. CASING WHILE DRILLING

CWD is a drilling process by replacing the use of conventional drill pipe with standard casing as the drill string, therefore the well can be drilled and cased simultaneously. After required depth is reached, the well is cased using the same casing directly.

CWD has been widely applied in the oil and gas drilling operation. This technology is generally used in the condition for the likes of wellbore instability and loss circulation problems. Over 200 wells have been drilled with casing drilling rigs and it was concluded that CWD reduced the loss circulation and non-productive time, Limbert (2009).

2.1. Benefit of CWD

- No needs to trip the drill string because the casing is already set in the desired depth and ready to be cemented. This eliminates swab and surge pressure in tripping operations. It reduces drilling time as well.
- Produces more circular and gauges wellbore by the smoothing motion of the well because the annular between the casing and the wellbore is smaller than conventional drilling.
- Generates more effective borehole cleaning. CWD has smaller clearance between the casing and borehole wall that cause high annular velocity and increased the borehole cleaning efficiency. Consequently, it reduces stuck pipe possibility.
- Reduces loss circulation and improves wellbore stability. The limited annulus causes the casing to smear the cuttings and drilling fluids against borehole wall when it rotates. It will make an impermeable barrier and seals the borehole wall, Martinez (2008). Smear effect potentially solves wellbore stability problems, kicks, vibrations, high torque and lost circulation, and it also reduces the risk of stuck pipe.
- Reduces possibility of well control incident since it has no tripping whereas well control problems often occur while tripping the drill string.
- If casing gets stuck before reaches desired depth, it can be set and cemented in that point. It will be more effective and efficient than pulling a drill pipe out of hole with probability of fishing. Meanwhile, the unreached depth can be covered by smaller dimension of casing but it can be operated safely.

2.2. Casing While Drilling Process

In CWD operation, casing is used as the drill string. The mechanical and hydraulic energy are provided by a top drive mechanism to the casing string and its pilot bit. Same as conventional drilling, drilling fluid is circulated down through the drill string and circulated up through the annulus. Generally, CWD bottom hole assembly (BHA) consists of a pilot bit, stabilizer, underreamer, and drill lock assembly (DLA). DLA is a tool to connect the drilling assembly to the casing strings and seal the connection hydraulically.

Two basic types of CWD systems are:

- **Retrievable system**
Retrievable system means that the BHA that connected to the first joint of casing string with DLA can be retrieved with wireline unit (wireline retrievable system) or drill pipe if the desired target depth is reached.
- **Non-Retrievable system**
In this system, BHA is not retrieved otherwise it is cemented immediately after reaching the desired depth and the bit is drilled out if the drilling process needs to continue. Common bit used in this system is drillable polycrystalline diamond compact (PDC) bits.

Figure 2 shows a retrievable and non-retrievable casing drilling BHA.

2.3. Plastic/Smear Effect

The wellbore annulus is obviously smaller when drilling with casing. This results an effect to the wall of wellbore called plastic/smear effect. Plastic/smear effect is a unique feature of CWD which can stabilize wellbore, prevent lost circulation and mitigate formation damage. This effect smears drilling cutting into formation and reduce the permeability of formation near wellbore, so it will not let drilling fluid enter the formation and prevent losses.

In geothermal field, when loss circulation becomes main problem because of the fractures, this effect can be a solution to solve this problem. The small annulus will smear drill cutting to the wall of wellbore, creates chances to reduce the pores or fractures permeability, prevents loss of drilling fluid to the formation and solves the loss circulation problem.

3. GEOTHERMAL CASING WHILE DRILLING CONSIDERATION

There are some considerations in CWD, however some of them such as borehole stability, well control, directional planning, and bit selection are similar with conventional drilling. Two significant differences are the casing may be subjected to different stresses in CWD and high temperature from geothermal energy. The second reason will reduce the casing strength. Therefore buckling, fatigue and hydraulics deserves special attention. Figure 3 shows interactions that affect the integrity of casing used for casing drilling, Warren (2001).

3.1. Temperature Effect on Casing Design

Knowledge about temperature in formation and wellbore is very important because of its influence on casing design. Temperature gives effects on casing especially if the temperature is high which is occurred in geothermal field. Neutral temperature is temperature which does not cause tension or compression on casing. If casing temperature is higher than neutral temperature, casing will be compressed while casing temperature is lower, it will be on tension condition.

$$T_n = T + 38 + \frac{\sigma}{\beta E} \quad (1)$$

Where:

- T_n : Neutral temperature (°C)
- T : Well temperature (°C)
- Σ : Axial tension (bar)
- β : Linear thermal expansion coefficient (1/°C)
- E : Metal elasticity modulus (bar)

Minimum temperature is calculated by differencing T_n with minimum temperature range which is calculated using equation:

$$\Delta T_{min} = \frac{Y_p}{\beta E} \quad (2)$$

Where

- ΔT_{min} : Minimum temperature range from neutral temperature (°C)
- Y_p : Casing yield point (bar)

By the definition, minimum temperature on casing

$$T_{min} = T_n - \Delta T_{min} \quad (3)$$

While maximum temperature range

$$\Delta T_{max} = \frac{R_1 R_2 Y_p}{\beta E} \quad (4)$$

R_1 and R_2 are constant which is generally 1.1 and 0.85.

3.2. Metal Mechanical Characteristic

Temperature interaction on metal will make influences on its characteristic. Metal mechanical characteristics relate with strength, hardness, tenacity and rigidity. Temperature has a great influence on metal characteristic especially on molecule bonding. Higher temperature on metal, molecule bonding will be weaker.

Metal mechanical characteristic which is related to casing design calculation are stress, strain, and elasticity modulus. Stress is strength of metal that accepts external loads per units of area. Strain is a difference of metal when accepts external tension load compared to initial condition. Meanwhile, Young Modulus is a ratio between stress and strain. All of metal mechanical characteristics can be formulated:

$$Stress = \sigma = \frac{F}{A} \quad (5)$$

Where:

σ : Stress, bar
 F : Given load, N
 A : Area, m²

$$Strain = \varepsilon = \frac{\delta}{L} \quad (6)$$

Where:

ε : Strain
 δ : Elongation, m
 L : Initial length, m

$$E = \frac{stress}{strain} = \frac{F/A}{\delta/L} \quad (7)$$

Elasticity modulus value is influenced by temperature, especially on high temperature condition in geothermal wells, stated in this equation below.

$$\frac{E}{E_o} = \left\{ \begin{array}{l} \left[1.0 + \frac{T}{c_9 \ln \left(\frac{T}{c_{10}} \right)} \right] \\ \frac{c_{11} - c_{12}T}{T - c_{13}} \end{array} \right. \quad (8.1)$$

$$\begin{array}{ll} c_9 = 2,000 & c_{11} = 690 \\ c_{10} = 1,100 & c_{12} = 0.69 \end{array}$$

Equation (8.1) can be used for

$$0 \text{ } ^\circ\text{C} < T \leq 600 \text{ } ^\circ\text{C}$$

Equation (8.2) can be used for

$$600 \text{ } ^\circ\text{C} < T \leq 1,000 \text{ } ^\circ\text{C}$$

Temperature influence on metal is shown below.

$$\delta = \alpha L \Delta T \quad (9)$$

Where:

α : Thermal expansion coefficient (1.24 x 10⁻⁵/°C)
 ΔT : Temperature change on metal, °C

If equation 11, 12, and 14 is merged, it will be shown below.

$$\sigma = \alpha E \Delta T \quad (10)$$

Equation above shows temperature relationship with stress of metal.

3.3. Casing Characteristic

Based on API 5 CT, casing characteristic is determined by yield strength, outer diameter, inner diameter, joint, collapse rating, and tension rating. Because of high temperature on geothermal wells, yield strength rating should be corrected using this equation.

$$\frac{\sigma}{\sigma_{yield}} = 1 - \frac{(T - 80)}{640} \quad (11)$$

Where:

T : casing temperature above 80 °C

σ_{yield} : yield strength, bar

If $T < 80$ °C, then $\frac{\sigma}{\sigma_{yield}} = 1$

3.4. Formation Hardness Effect

Geothermal formation is harder than oil and gas formation. It will cause some effect well planning such as casing design, bottom hole assembly selection, trajectory planning.

In geothermal casing drilling operation, the torque and drag will be much higher because of smaller annulus. Smaller annulus means a close gap between drill string and borehole wall and facilitate the occurrence of contact between drill string and borehole wall. In addition, it has to cope with the harder formation. Since the formation is harder and abrasive, if this contact is too much happened, it will make casing wear faster and reduce casing lifetime as well.

Hard formation will also lead to the different BHA that used especially the bit selection. Bit selection has a big effect on rate of penetration (ROP) and drilling time. In the directional drilling program, casing drilling with retrievable system is used. In this system, the time to pull out the BHA will be longer than conventional drilling because it needs to unlock the BHA from the DLA. Therefore, bit program has to be designed precisely.

When directional well will be applied, the trajectory program used in geothermal casing drilling need more attention. In oil and gas casing drilling, some of the actual well paths are deviated from the planned. It is caused by drill string that used is more rigid and more difficult to be deflected. Generally, casing drilling creates lower buildup section than planned trajectory. In the harder formation, path control will be more difficult.

3.5. Buckling

The bottom of the casing is capable of accommodating restricted compressive load prior to buckling, Cummins (2007). Buckling is the result of bending moments that created by the casing/hole geometry and compressive load on the casing making it unstable. It makes the casing cannot support the compressive loads except with lateral support which may not result in structural failure of the casing, Gaurina-Medimurec (2005). For straight holes, buckling is caused by compressive load, which is established by gravity force (inclination and weight of pipe), pipe stiffness (EI) and radial clearance (distance from the borehole). In deviated wells, drill string stability increases with inclination increase. This comes from the axial compression which forces the string to the outside of the curve thereby helping gravity in keeping the string firm against the wall of the borehole, Gaurina-Medimurec (2005).

Buckling will not occur since the critical buckling is not reached. Buckling occurs when the applied compressive force exceeds the pipe's critical buckling load. The critical buckling force is the minimum compressive force that caused the pipe buckling. The critical buckling force is given by:

$$F_c = 550 \times \left[\frac{I \times W_{string} \times (65.6 - M_w) \sin \theta}{(D_H - D_{TJ})} \right]^{\frac{1}{2}} \quad (12)$$

Where:

- F_c : Critical buckling force, lb
- I : Moment of inertia of pipe, in⁴
- A_s : Cross sectional area of pipe, in²
- OD : Outside diameter pipe body, in
- ID : Inside diameter pipe body, in
- W_{string} : Weight of drill string in air, lb/ft
- M_w : Mud density, ppg
- DH : Hole diameter, in
- DTJ : Diameter of tool Joint, in
- θ : Hole angle, degree

3.6. Fatigue

Fatigue failure is the result of cyclical loading at stress levels, which are much lower than the elastic limit. By continuous loading, a little crack starts to occur at the high stress region and spreads to the entire body until the left cross sectional area is inadequate to carry the static load. Drill string failures stem from oscillatory bending loads. They are usually found at the bottom of the drill string and not at the upper part where the static tensile stresses are greatest. Occasionally, a fatigue crack precedes the final rapture. These failures are either located in the slip portion of the drill pipe or within the threaded area of the connection, Cummins (2007).

3.7. Vibration and Critical Rotary Speed

Drill string vibration occurs when the frequency of the applied force equals to the drill string natural vibration frequency. Rotation of the drill string at its natural resonant frequency results in excessive and rapid wear of the drill string and can result in premature fatigue failure, Aryanto (2013).

Drill string vibration can be reduced by:

- Modifying the drilling parameters (revolution per minute/weight on bit)
- Applying mechanical damping of the string via the use of a shock sub
- Avoiding rotating the string at the natural resonant frequency of the drill string.

Critical rotary speeds calculation for each assembly run should be performed to ensure that rotational speed does not result in generation of harmful resonant vibrations. The methods used for the determination of critical rotary speed are quite complex and require the solution a complex set of equations.

The critical rotary speed may be predicted approximately by the formula, Murchison Drilling school book (1988):

$$RPM = \frac{4,760,000 \times (D^2 + d^2)^{1/2}}{l^2} \quad (13)$$

Where:

- RPM : Critical Speeds, revolution/minute
 l : Length of one joint, inch
 D : Outside diameter, inch
 d : Pipe/casing inside diameter, inch

This formula is probably accurate within 15%. On this basis the following rotary speeds should be avoided by at least 15% (higher or lower).

3.8. Hydraulic

Another difference between the conventional and casing drilling lies in the geometry provided by the fluid flow path. High casing internal diameter caused the path down unrestricted resulting in a very small pressure loss within the internal of the casing. Otherwise, the casing while drilling annulus which is smaller than conventional drilling annulus provides a bigger restricted flow path causing higher pressure losses. In the other hand, it generates more effective borehole cleaning.

3.9. Torque and Drag

The torque generated when running casing strings is as a result of the frictional forces acting between the wellbore and the casing. The torque and drag for casing drilling is usually higher than that of conventional drilling since the casing experiences certain wellbore issues such as sloughing shale, tight-hole conditions, differential sticking and sliding during drilling process, Hossain and Amro (2004). The size and weight of the casing is also greater than the drill pipe. Since geothermal formation consists of igneous and metamorphic rock which is hard formation, torque and drag would be much higher.

This would be critical to the operation to ensure that the additional torque would not exceed the torsional yield limits of the casing or exceed the make-up torque of the connection. Also, to confirm that the axial load capabilities of the casing would not be breached at any pint. Therefore, the extensive pre-job modeling has to be conducted by the casing and CWD providers so enable actual values to be as close as possible to predict.

The torque and drag consideration is very essential in determining the suitability of a well (especially directional well) for casing drilling.

All the several propriety software packages use essentially the same equations for calculating torque, drag and buckling forces. The following equations may be used to carry out the above calculations:

Torque for straight section of hole:

$$T = \frac{OD \times W_m \times L \times \mu \times \sin \theta}{24} \quad (14)$$

Torque for buildup curve section:

For $WOB < 0.3 \times W_m \times R$, torque value is given by:

$$T_H = \frac{OD \times W_m \times R}{72} \quad (15)$$

For WOB > 0.3 x W_m x R, torque value is given by:

$$T_H = \frac{OD \times W_m \times R}{144} + \frac{OD \times WOB}{46} (WOB - 0.33W_m R) \quad (16)$$

Where:

- T : Torque, lb-ft
- WOB : Weight on bit, lb
- OD : Outside diameter of tool joint (Coupling), inch
- W_m : Average pipe buoyant weight, lb/ft
- L : Length of hole or pipe section, ft
- R : Build up radius, ft

4. RISK ANALYSIS

Most of risk using casing drilling in geothermal are similar with casing drilling applied in oil and gas drilling operation. Some of these risks are:

- In geothermal drilling operation, high temperature reduces the surveying tool efficiency.
- It needs higher casing strength because casing strength will be reduced by high torque and drag while drilling and also high temperature. using retrievable system, there is no possibility high temperature. Using retrievable system, there is a possibility of BHA to stick in hole when pulling it out.
- It needs high torque connection since geothermal well has a hard formation that increase torque and drag.

5. CONCLUSIONS

Casing drilling method has been successfully applied in oil and gas Industry with all of benefits. This success and all of benefits will be developed in geothermal operation. The study about developing this method in geothermal operation brings several conclusions.

- Geothermal formation has different characteristic than common oil and gas formation, such as high temperature, hard rock and fractured formation that has to be considered within casing drilling design.
- Loss circulation is one of main problems in geothermal drilling operation which leads to loss of drilling fluid, reduce quality of production ability, cutting will not be transported to surface, and stuck pipe. However, it can be solved by the benefit of casing drilling plastic/smear effect.
- Based on API 5 CT, casing characteristic is determined by yield strength, outer diameter, inner diameter, joint, collapse rating, and tension rating. It should be corrected due to high temperature on geothermal wells.

6. REFERENCES

- API Spec 5CT: Specification for Casing and Tubing, American Petroleum Institute. (2011).
- Aryanto: Integrated Evaluation of Directional Casing Drilling in 'YY' Field Offshore of Indonesia, Thesis of Master Degree of Petroleum Engineering, Institut Teknologi Bandung, Indonesia (2013).
- Cacini, P. and Mesini, E.: Rock-Bit Wear in Ultra-Hot Holes, SPE28055, presentation at the SPE/ISRM Rock Mechanics in Petroleum Engineering Conference, Delft, Netherlands, August 29–31th, (1994).
- Cummins, T.: Top-drive Casing-Running Tool Solves Tough ERD Problems, Journal of Petroleum Technology, 59 (2007).
- Finger, J., et al.: Handbook of Best Practices for Geothermal Drilling, Sandia National Laboratories, California, USA (2010).
- Gaurina-Medimurec, N.: Casing Drilling Technology, Rud-geol-naft. Zb, 17(1), (2005), 19-26.
- Holligan, D., Cron, C.J., Love, W.W., and Buster, J. L.: Performance of Beta Titanium in a Salton Sea Geothermal Production Well, SPE18696, presentation at the 1989 SPE/IADC Drilling Conference, New Orleans, Louisiana, (1989).
- Hossain, M. M. and Amro, M. M.: Prospects of Casing While Drilling and The Factors to be Considered During Drilling Operations in Arabian Region, Proceedings at the SPE/IADC Asia Pacific Drilling Technology Conference and Exhibition, Society of Petroleum Engineers, Texas (2004).

Marbun et al.

- Kesuma: Drilling Practice with Aerated Drilling Fluid: Indonesian and Icelandic Geothermal Fields, UNU-GTP, Iceland (2008).
- Limbirt, D., et al.: Evolution of Drillable PDC Technology Enables Operators to Safely and Economically Drill South Texas Gas Wells with Casing, SPE/IADC 119422, Amsterdam, Netherlands, (2009).
- Marbun, B., Aristya R., Pinem R.H., Rambli, B.S., Gadi, K. B: Evaluation of Non Productive Time of Geothermal Drilling Operations – Case Study in Indonesia, 38th Workshop on Geothermal Reservoir Engineering, Stanford University, CA (2013).
- Marbun, B., Ekasari, N., Asri, M.: Bit Performance Evaluation: A Case Study In “X” Geothermal Field In Indonesia, Proceeding 2nd ITB Geothermal Workshop 2012, Institut Teknologi Bandung, Indonesia, (2012).
- Marbun, B., and Zulkhifly, S.: Geothermal Well Integrity, Proceeding 11th Annual Meeting and Conference, Indonesia Geothermal Association, Lampung (2011).
- Marbun, B., Zulkhifly, S., Priatmojo, S., and Gunawan, T.: Selection of Best Drilling Design for Geothermal Drilling – Case Studies, Proceeding 36th Annual Convention & Exhibition, Indonesian Petroleum Association (2012).
- Marbun, B., Zulkhifly, S., Hariz, I., and K. Dita: Geothermal Drilling – An Overview, Proceeding 35th Annual Convention & Exhibition, Indonesian Petroleum Association (2011).
- Martinez, J. F., et al.: Casing While Drilling Results in Safer Drilling, Larger Wellbores, World Oil, 229 (4) (2008).
- Murchison, W. J.: Rules of Thumb for The Man on The Rig, Murchison Drilling School, Inc. Albuquerque, New Mexico (1988).
- Purba, N. P.: A New Integrated Evaluation Method of Drilling Design and Operational of Geothermal Well, Bachelor Thesis of Petroleum Engineering, Institut Teknologi Bandung, Indonesia (2013).
- Warren, T. et al.: Casing Drilling Technology Moves to More Challenging Applications, Proceedings of the AADE National Drilling Conference, Texas (2001).
- Warren, T., and Lesso, B.: Casing Directional Drilling, Proceedings of the AADE National Technical Conference and Exhibition, Texas (2005).

7. APPENDIX

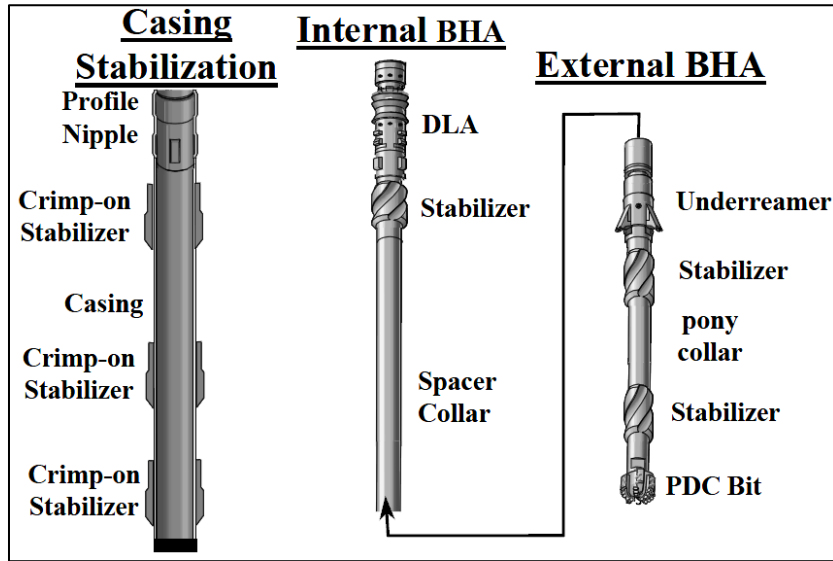


Figure 1: Casing drilling BHA, Warren (2005).

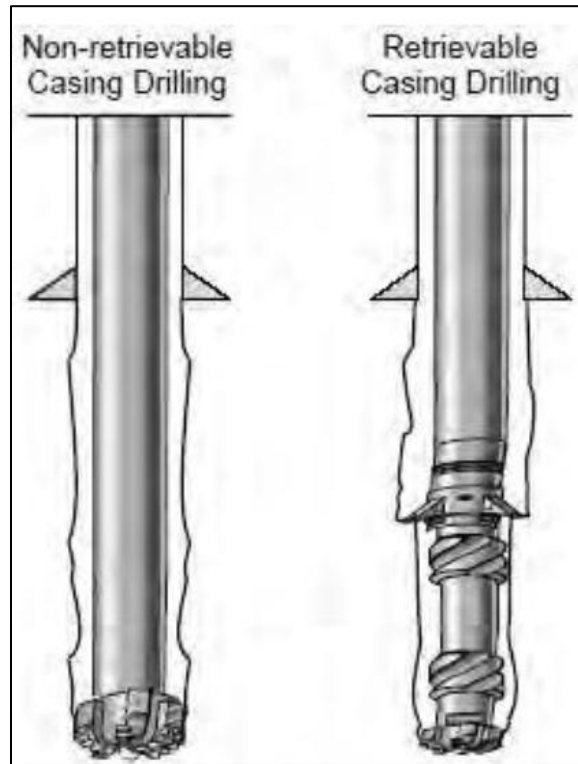


Figure 2: Non-retrievable and retrievable casing drilling BHA, Robinson (2008).

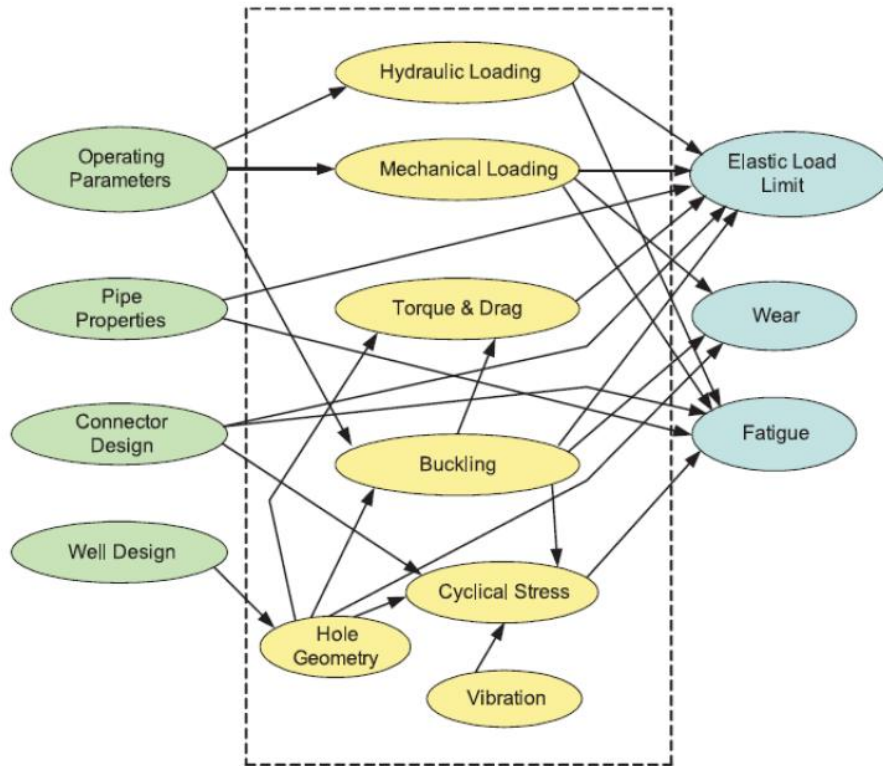


Figure 3: Interactions affecting casing integrity for Casing drilling applications, Gaurina-Medimurec (2005).